national accelerator laboratory

TM-294
0400

PARTIAL-APERTURE BEAM "ABORT" SYSTEM FOR MAIN RING

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April 12, 1971

This is a design based on the concept presented by A. W. Maschke of a partial-aperture beam abort system for the Main Ring. This concept was discussed at a meeting on April 5, 1971 attended by:

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The partial-aperture system is easier and cheaper to build and may be used as an initial system.

RATIONALE

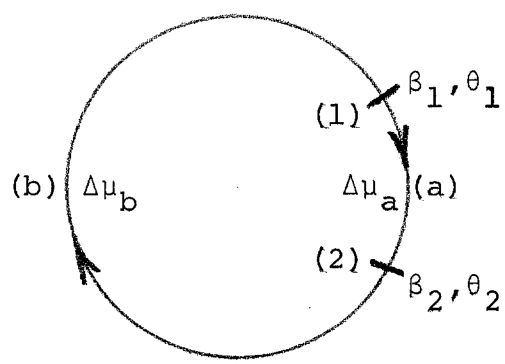
The main ring beam abort system studied and designed so far (L. C. Teng, FN-195, and "Beam Abort System for the NAL 500 BeV Synchrotron," J. A. MacLachlan, Jr., T. A. Borak, L. C Teng and F. C. Shoemaker, paper presented at the 1971 Particle Accelerator Conference in Chicago) is a full-aperture system where the full aperture of the main ring is bumped vertically out of itself by pulsed magnets.

Since the extraction septum is located 3 cm horizontally outward from the center of the aperture it is likely that no more than ±3 cm of the horizontal aperture will be used. If we define the aperture used by the beam to be 6 cm(h) x 4 cm(v) the beam abort system can be significantly simplified. With the excess horizontal aperture available it is now advantageous to bump the beam horizontally using 2 pulsed magnets placed an integral number of half wave lengths apart. In addition, the aperture of the pulsed magnets can be reduced to 6 cm x 4 cm.

The price one has to pay for using this partial-aperture abort system is, of course, that the usable aperture of the main ring is now limited to 6 cm x 4 cm, at least at the positions of the pulsed magnets.

ORBIT GEOMETRY

(We are interested only in the horizontal plane. The subscript x on all quantities is omitted as being understood.)



Two pulsed magnets producing orbit angular deflections θ_1 and θ_2 are located around the ring where the amplitude function has values β_1 and β_2. The phase advance from 1 to 2 is $\Delta\mu_a$ and from 2 to 1 the other way around is $\Delta\mu_b$. Then

$$\Delta\mu_a + \Delta\mu_b = 2\pi\nu \tag{1}$$

The displacement anywhere in regions a and b are given by

$$
\begin{cases}
x_a = \dfrac{\sqrt{\beta_a}}{2\sin\pi\nu}\left[\left(\theta_1\sqrt{\beta_1}+\theta_2\sqrt{\beta_2}\right)\cos\dfrac{\Delta\mu_b}{2}\cos\mu_a\right. \\
\qquad\left.+\left(\theta_1\sqrt{\beta_1}-\theta_2\sqrt{\beta_2}\right)\sin\dfrac{\Delta\mu_b}{2}\sin\mu_a\right] \\
x_b = \dfrac{\sqrt{\beta_b}}{2\sin\pi\nu}\left[\left(\theta_1\sqrt{\beta_1}+\theta_2\sqrt{\beta_2}\right)\cos\dfrac{\Delta\mu_a}{2}\cos\mu_b\right. \\
\qquad\left.-\left(\theta_1\sqrt{\beta_1}-\theta_2\sqrt{\beta_2}\right)\sin\dfrac{\Delta\mu_a}{2}\sin\mu_b\right]
\end{cases}
\tag{2}
$$

where the phase advances μ_a and μ_b are measured from the middle points of regions a and b, respectively. From Eq. (2) one observes that to have $x_b = 0$, namely, the beam undisturbed in region b, one must have either

$$\theta_1\sqrt{\beta_1} = \theta_2\sqrt{\beta_2} \qquad \text{and} \qquad \Delta\mu_a = \text{odd } \pi \tag{3}$$

or

$$\theta_1\sqrt{\beta_1} = -\theta_2\sqrt{\beta_2} \qquad \text{and} \qquad \Delta\mu_a = \text{even } \pi \tag{4}$$

PLACEMENT OF PULSED MAGNETS IN LATTICE

The requirements are:

a. $\Delta\mu_a$ should be close to integer times π.

b. There should be a long straight (say DL) in region a for placing the dump target.

c. The pulsed magnets should be placed at high β locations. It is preferable to have $\beta_1 = \beta_2$ because, then, the two pulsed magnets can be identical.

The β and $\frac{\mu}{2\pi}$ at various straights in the neighborhood of DL are given below

Station No. (Old System)	β(m)	$\frac{\mu}{2\pi}$	Pulsed Magnet
C30	28	-0.436	
C31	96	-0.342	(1)
C32	28	-0.239	
C33	96	-0.146	
C34	62	-0.087	
(D0-)	47	-0.071	
D0	70	0	
(D0+)	120	0.043	
D1	95	0.051	
(D1+)	62	0.061	
D2	28	0.188	
D3	96	0.281	
D4	28	0.384	
D5	96	0.478	
D6	28	0.581	
D7	96	0.675	(2)
D8	28	0.778	

where the additional stations in parentheses are

(D0-) upstream end of the 51 m long-drift

(D0+) downstream end of the 51 m long-drift

(D1+) 3 m ministraight immediately downstream of the 4 matching quads.

To get high and identical β_1 and β_2 we have to go to $\Delta\mu_a \simeq 2\pi$ and $\theta_1 = -\theta_2$ [case described by Eq. (4)]. The best arrangement for which the upstream end of the dump target located approximately at station (D0-) is at a phase advance of $\frac{\mu}{2\pi} \simeq \pm\frac{1}{4}$ from either magnet is shown by the bracket in the above table.

Two identical pulsed magnets oppositely excited are placed in the ministraights at C31 and D7 where $\beta_1 = \beta_2 = 96$ m and $\Delta\mu_a = 1.017(2\pi)$. The dump target starts at (D0-) and extends (not necessarily continuously) all through the 51 m long-drift.

PULSED MAGNETS

With this arrangement $\beta_1 = \beta_2 = 96$ m, $\Delta\mu_a = 1.017(2\pi)$, $\Delta\mu_b = 2\pi\nu - \Delta\mu_a = (20.25-1.017)(2\pi) = 19.233(2\pi)$, $\theta_1 = -\theta_2$ and we have from Eq. (2)

$$\left\{\begin{aligned} x_a &= -9.26\ \theta_1\sqrt{\beta_a}\ \sin\mu_a \\ x_b &= \ \ 0.74\ \theta_1\sqrt{\beta_b}\ \sin\mu_b \end{aligned}\right. \tag{5}$$

Because $\Delta\mu_a$ is not exactly 2π, x_b is not exactly zero. But since $(\beta_a)_{max} = (\beta_b)_{max}$ we have

$$\frac{|x_b|_{max}}{|x_a|_{max}} = \frac{0.74}{9.26} \simeq 8\% \tag{6}$$

which is quite acceptable. We could make $x_b = 0$ by adding a third pulsed magnet but this appears to be unnecessary.

A horizontal aperture of 6 cm at the extraction septum (station C33-equivalent where $\beta = 96$ m) is equivalent to a horizontal aperture at the upstream end of the dump target (station (D0-) where $\beta = 47$ m) of

$$(6\ \text{cm})\sqrt{\frac{47}{96}} = 4.2\ \text{cm}. \tag{7}$$

To obtain a displacement of $x_a = 4.2$ cm at the upstream end of the dump target where $\beta_a = 47$ m and

$\mu_a = \left| (-0.071 + 0.342) - \frac{1.017}{2} \right| (2\pi) = -0.475\ \pi$ we get from Eq. (5)

$$\theta_1 = 0.663 \text{ mrad} = -\theta_2 \tag{8}$$

For 200 BeV with $B\rho = 6702.5$ kGm this gives for the pulsed magnet

$$B\ell = 4.446 \text{ kGm} \qquad (200 \text{ BeV}) \tag{9}$$

and for 500 BeV with $B\rho = 16709.5$ kGm this gives

$$B\ell = 11.083 \text{ kGm} \qquad (500 \text{ BeV}). \tag{10}$$

The parameters for the magnet are, then

$$\begin{cases} \text{Aperture} = 6 \text{ cm(h)} \times 4 \text{ cm(v)} \\ \text{Length} = \ell = 1 \text{ m} \\ \text{Peak field} = B = \begin{cases} 4.5 \text{ kG} & \text{for 200 BeV} \\ 11.1 \text{ kG} & \text{for 500 BeV} \end{cases} \\ \text{Rise time } (\frac{1}{4} \text{ sine wave}) = 1 \text{ msec} \end{cases} \tag{11}$$

(The rise should be faster than all conceivable beam loss mechanisms. Further studies are needed to firm up the assumed 1 msec rise time.)

PULSED MAGNET POWER SUPPLY

Assuming that the magnet coil has N turns we get

	200 BeV	500 BeV
Peak stored energy U	193.4 J	1176.6 J
Peak Current I	$\frac{14.3}{N}$ kA	$\frac{35.3}{N}$ kA
Inductance L	$1.885\ N^2\ \mu H$	$1.885\ N^2\ \mu H$
Capacitance C	$\frac{215}{N^2}$ mF	$\frac{215}{N^2}$ mF
Charging Voltage V	42.4N V	104.6N V

Taking N = 10 we get

	200 BeV	500 BeV
I	1.43 kA	3.53 kA
L	188.5 μH	188.5
C	2.15 mF	2.15 mF
V	424 V	1046 V

The capacitor is trivial and the switching can be accomplished easily and reliably with SCR's.

DUMP TARGET

Now with the full 51 m long-drift length available the target can be made of low Z material, possibly aluminum. It could be constructed in sections, say, 6 m long each. It could be shaped like a wide vertical collimator. The jaws could be 3 cm thick horizontally and 6 cm high and separated horizontally by 4.2 cm at the upstream end. The separations downstream would be tailored to the beam displacement.

The efficiency of the dump target at this slow bump rate should be investigated.